TELEMETRY OF BIOLOGICAL INFORMATION

A Thesis submitted

in partial fulfilment of the requirements

for the Degree of

Master of Technology

by

K. SIVARAM

to the

Department of Electrical Engineering

Indian Institute of Technology

Kanpur

May 1968

This is to certify that this work on Telemetry of Biological Information has been carried out under my supervision and it has not been submitted elsewhere for a degree.

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This thesis has been approved for the award of the Degree of Master of Technology in accordance with the regulations of the Indian Institute of Technology, Kanpur.

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SYNOPSIS

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A literature on Electronic Instrumentation for biomedical applications is reviewed. A critical comparison of the present systems of radio transmission is included. Requirements of subsystems for biological data acquisition, transmission and reception are also discussed.

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CHAPTER I

IMPORTANCE OF TELEMETRY

An electronics engineer can assist a medical man by blending his technical knowledge with an understanding of biology, surgery and the actual problems of the physician. Presently a physician bases his diagnosis upon two pieces of information. One is the patient's version of his troubles and the other is obtained with the aid of equipments with which he measures some variables of the human body. The patient's version is often very inaccurate. So the modern trend is to increase the doctor's tool kit so that he can make objective diagnosis by measuring more variables of the human body.

It is quite possible to swallow or implant in various body cavities, measuring devices and miniature radio telemetering transmitters which will perform certain measurements for example it is quite a discomfort for the patient to receive stomach examination by means of gastroscope, gastrocamera or others or to collect the stomach juice through a rubber tube. Moreover, it is questionable whether the result of examination obtained under such conditions can be reliable, since, as it is well known, stress on the human body affect the reliability of data collected.

If the measurements could be made with the patient in a

easy condition, namely, in one as close to their natural condition as possible, and if examinations could even be made within the intestinal tract, the digestive organs could be investigated easily and further findings, new and unknown, might be obtained. This example gives one of the practical uses of implanted telemetry. These implantable transmitters are important in the study of human beings because they leave the subject in a relatively normal physiological state and they are atleast as important in animal study where discussion and cooperation is impossible.

1.1 ROLE OF TELEMETRY IN BIOLOGICAL SCIENCES:

One of the problems confronting every biologist engaged in research in the natural environments is obtaining continuous, accurate and simultaneous measurements on a variety of parameters. The biologists often obtain information which is incomplete for reliable statistical analysis. A possible improvement in this situation lies in the field of interdisciplinary research in which the engineers and biological scientists apply their combined resources to obtain measurements of the natural environment. It is obvious that much of ecology (study of life in relation to its environment) requires quantitative data which may be obtained only through cooperative studies in biotechnology including the use of telemetry.

If in the course of a scientific investigation in the fields of biological sciences, a measurement is to be made, we can distinguish several steps of action to take place. There may

be first a sociological or a physiological event which may lead to a biological response, or a pattern of such responses - for instance the secretion of Adrenalin will lead to a physical or a chemical change inside the test object or on its surface, such as the apparent change of electrical resistance of the skin. Once the physical change has occurred we can measure it, that is, we can apply a certain type of instrumentation element which converts the physical change into a useful signal. In general a measuring process is not completed by converting the physical or chemical change into a signal; in order to obtain the desired information the signal must be processed, that is amplified or attenuated, filtered, integrated and so on by means of further instrumentation. The transducers available for converting a physical or chemical change into a useful signal is limited. But we are interested in transducers that convert a physical phenomena into electric signal. A few transducers used are shown in the Table below.

Physical Quantity	Transducer for converting into an electric signal
Mechanical	Piezo electric crystal
Thermal	Thermistor
Magnetic	Magneto resistance
Optic	Photo electric cell
Nuclear	Geiger counter

CHAPTER II

ENGINEERING ASPECTS OF TELEMETRY

The engineering aspects of a system for gathering and processing biological information are similar to that of any information gathering system. The scope of the systems may be divided into four essential parts. Biological data acuisition, Data processing, Data transmission and Information processing.

2.1 BIOLOGICAL DATA ACUISITION:

Before considering the sensors to be used let us consider some of the most frequently measured biological parameters.

2.1.1 Electro cardiography:

The pumping action of the heart is produced by the action of the heart muscle. The contraction of this muscle is accompanied by electrical potential changes which are conducted all over the body. In electro cardiography, these potential changes are recorded and their pattern is used in the diagnosis of the diseases of the organ.

2.1.2 Blood Pressure:

The arterial blood pressure is an integration of multiple physiological inputs into the cardiovascular (pertaining to heart and blood vessels) system. The only

problem with this measurement is the tendency of the living tissue to reject or encapsulate and isolate any foreign material. There is also a possibility of generation of blood clots in the blood stream.

2.1.3 Myoelectric Potential:

The record obtained by recording the changes in the electric potential of the muscle (1) by means of surface or needle electrodes to determine merely whether the muscle is contracting or not (2) by insertion of a needle electrode into the muscle and observing by Cathode Ray Oscilloscope the action potentials spontaneously present in the muscle (3) by recording of the electrical activity evoked in a muscle by the stimulation of its nerve is called an electromyogram.

2.1.4 Encephalo electric Potentials:

The record of activity in the brain is known as electroencephalogram. In this the electric potential variations produced by synchronous discharge of systems of nerve cells in the brain are recorded via amplifiers connected to electrodes on the scalp which sample the resulting electric field. It is used as an routine investigation to assist the diagnosis of various forms of epilepsy, brain tumours and other diseases affecting the central nervous system.

2.1.5 Temperature:

This is a unique measurement in that it defines the activities of the cellular metabolism (the chemical changes continually going on in the cells of living matter) within the body. For example, temperature of blood leaving the liver is an indicant of the metabolic process taking place in that organ. The temperature of the muscle bundle increases with the tension of the activity of the muscle. The significance of temperature measurements lies in the fact that it is a dynamic measure of the oxidative process taking place in the body. As such it is a direct indicant of the energies being spent, the thermal storage capacity of the body and the adequacy of the thermo-regulatory system.

Specifications data for the measurements of:

Parameter	Sensitivity	Frequency response	Source impedance
1) E.C.G.	1 mv/cm.	0.1 to 100c/s	500 ohms to 5 k.ohms
2) E.M.G.	0.1 to 4 mv/cm.	2 c/s to 100 k.c/s	-do-
3) E.E.G.	10 to 200 microvolt/cm.	1 to 100 c/s	-do-
4) Temperature	Depends on sensor sensitivity (sensor should be sensitive in the range of 90° to 110°F)	DC to 1 c/s	-do-

2.2 REVIEW AND SELECTION OF SENSORS:

2.2.1 E.C.G., E.M.G., E.E.G. electrodes:

Physical requirements of these electrodes are that the material must be an electrical conductor and biologically inert. Gold, platinum and stainless steel are used for electrodes. The stainless steel is proving satisfactory for implanted applications. The electrode shape is not of great electrical significance.

2.2.2 Temperature:

The use of thermistor for measuring body temperature is unanimously accepted. There are some few exceptions where circuit design makes use of the temperature sensitivity of a transistor or capacitor in order to vary the amplitude or frequency of an oscillator. But, by and large, the thermistor is the preferred sensor for temperature. The output of a thermistor is logarithmic and must be linearised if the temperature is digitally displayed. But the narrow range of body temperatures simplifies the linearisation networks.

2.3. COMPARISON OF MULTIPLEX SYSTEMS FOR BIOLOGICAL RADIO TELEMETRY APPLICATIONS:

Various multiplex systems are compared on the basis of their functional properties like accuracy of signal reproduction, sensitivity to internal and external interferences, reliability of operation, power economy and size of the transmitting plant.

2.3.1 Time Division Multiplex Systems:

Accomplishment of the multiplex action in these systems is provided by discrete sampling of the information in the individual channels and further consecutive staggering of the samples in time for purposes of modulating the carrier link. Realization of the requirement set by the sampling theorem is not difficult when it comes only to a few biological channels (say less than four). Limitations arise when an increased number of multiplex channels is needed. For a givenperiod of sampling, the number of multiplex channels determines the duration of the staggering intervals and thus the repitition rate of the pulses modulating the carrier wave. This imposes the bandwidth requirement of the system. These requirements become stringent with the need for accurate preservation of the pulse shapes throughout their processing path. The ideal signal spectrum has to comprise components in a bandwidth which is the reciprocal of the pulse rise time. This means, practically speaking, inclusion of even the tenth harmonic of the fundamental pulse repitition rate. Such strong requirements are of decisive significance for the pulse position modulation and pulse duration modulation systems, as correct and distortionless separation of channels in the receiver depends on the accurate location of the pulse edges. Pulse amplitude modulation can be accomplished at lower bandwidth but it is not suitable for biological application due to poor discrimination of interference signal. When weighing the possibility of increasing the number of multiplex channels

a compromise has to be found between the two contradictory demands: the sampling rate and the bandwidth of the system.

2.3.2 Frequency Division Systems:

For the purpose of comparison of the time division multiplex systems with frequency division systems let us take for example a 4-channel time division multiplex system of 500 c/s bandwidth for handling biological data. An additional staggering inverval must be reserved for synchronisation purposes between the transmitter and the receiver. If one provides for a demodulation guard band of 200 pulses per second, the sampling rate for a given channel has to be 1200 pulses per second. This means modulation of the carrier by pulses, with 6000 pulses per second pulse repitition rate. Considering the mean pulse duration to be equal to about 1/3 of the pulse repitition interval, thus allowing for modulation displacements and guard intervals between the channels and also taking the rise time 1/3 of its duration, the required bandwidth amounts to

$$9 \times 6000 = 54000 \text{ c/s} \quad \text{or say nearly} = 55 \text{ kc/s.}$$

This is still a reasonable number for providing wide band F.M. high quality performance in the carrier link. Further extension of the multiplexed channels, assuming preservation of the carrier wide band F.M. quality could accomplished by lowering the sampling rate but this leads to an increase in the sampbing error and to inaccuracies in signal reproduction. This would become especially prominent for fast random biological activity, as of the E.E.G. or E.M.G.

As opposed to the time division multiplexing, no inherent information losses can be predicted for the continuous wave modulation in the frequency division systems while provision can be made for using more channels. For an A.M./F.M. system, the number of channels which might be comprised in the 55 kc/s bandwidth spectrum of the signal which modulates the carrier (in relation to the same bandwidth as considered for the pulse modulation example) is especially large.

For an F.M./F.M. system, equivalent to time division multiplex system in regard to suppression of interference signals, the number of channels can be extended to six.[1].

Moreover in the telemetering of biological phenomena of various kinds, a situation can be thought of where one or a few channels require higher bandwidth than others. In time division multiplex system the sampling rate has to be fitted to the highest frequency of the broadest channel. This causes the whole system bandwidth to rise proportionally to the bandwidth of this channel and leads to inefficiency in utilization of the system's information handling capacity. In frequency division multiplexing the system bandwidth can be used in a flexible manner as it is just the sum of the subsequent channel's bandwidths.

2.3.3 Comparison of systems from the point of view of discrimination against interferences

The possible advantage of amplitude modulation in

circuitry but these are susceptible to noise and crosstalk between channels. These factors are mostly in the form of amplitude changes and therefore cannot be discriminated from the processed genuine information.

The best properties are those in pulse code modulation systems but it is disregarded for our purpose due to its extreme complexity. The choice remains between carrier wave F.M., P.P.M. (Pulse position modulation) and P.D.M. (Pulse duration modulation). They all provide an increase of the S/N ratio over A.M. in proportion to the increase in bandwidth, but with the rising of the number of channels the proportionality factor becomes more favourable for a carrier wave F.M. This can be shown by using the formulas for improvement in noise in carrier wave F.M. and pulse amplitude modulation channels.[2], and developing them for presentation in a typical multiplex systems for handling biological information.

$$(S/N)_{FM} = \sqrt{3}\,\beta \quad (S/N)_{AM} \qquad (1) \quad [2]$$

$$(S/N)_{PPM} = \frac{t_o}{\sqrt{2}\;t_r}\left(\frac{S}{N}\right)_{PAM} \qquad (2) \quad [2]$$

But $(S/N)_{AM} = (S/N)_{PAM}$

where (S/N) is the voltage signal to noise ratio of a system designated outside parenthesis,

β is modulation index in F.M. ,

t_o is the maximum displacement from quiescent pulse

position in Pulse Position Modulation and

t_r is the rise time of the pulse.

Replacing $= \triangle f/f_m$

$\triangle f$ is frequency deviation and

f_m is highest modulating frequency

And taking spectrum bandwidth say B_{FM} as

$$B_{FM} = k(\beta)\triangle f \qquad (3)$$

where B_{FM} is spectrum bandwidth of the modulating signal and

$k(\beta)$ is some function of β.

Therefore $$(S/N)_{FM} = \frac{\sqrt{3}}{k(\beta)f_m}(S/N)_{AM} \qquad (4)$$

For the practical pulse position modulation system t_o can be assumed to be about 1/3 of the staggering interval between the consecutive channels and can be represented thus as

$$t_o = \frac{1}{3}\,\frac{1}{2.4n\,f_m} \qquad [1]$$

where n is the number of staggering channels and the factor 2.4 makes provision for the sampling rate and demodulation guard. Considering the spectrum bandwidth of the modulated signal is

$$B_{PPM} = \frac{1}{t_r}$$

and equation (2) becomes

$$(S/N)_{PPM} = \frac{B_{PPM}}{\sqrt{2}.\ 7.2\ n\ f_m}(S/N)_{PAM} \qquad (5)$$

Considering equations (4) and (5) it becomes evident that noise improvements in both systems taking the channel information bandwidth, taking f_m as constant, is proportional to the system of the modulated signals in a channel and also depends on the modulation index in F.M. and on the number of multiplexed channels in P.P.M. Equalising the proportionality factors it is found that

$$\frac{B_{FM}}{k(\beta)} = \Delta f = \frac{1}{17.6\,n}\,B_{PPM}$$

This means that for the particular example of the four channel (n = 5) biological multiplex system B_{PPM}=55 kc/s, the deviation in F.M. should be 625 c/s in order to provide the same noise improvement as in P.P.M. system.

It may be estimated that nearly the same relations for improvement of signal to noise ratio of the P.P.M. holds for P.D.M. system [1].

2.3.4 Crosstalk:

Regarding crosstalk between multiplexed channels, the carrier wave wide band F.M. systems provide significant improvement over A.M. and P.A.M. as well as over P.P.M. or P.D.M. of limited bandwidth under condition of linearity in the radio link. This condition is realizable in biological radio telemetry where low power transmitters are normally used.

The susceptibility of P.P.M. and P.D.M. systems to crosstalk results from the fact that transferred information is

contained here in the position of the pulse edges which are altered by distortion of the pulse shape. Other reasons in the favour of carrier wave F.M. multiplexing system is the simple modulation procedure.

The degree of simplicity in carrier wave F.M. can be favourably compared to that of A.M. The performance quality is secured by designing the subcarrier oscillators to be stable enough while simultaneously providing high modulation intensity.

In general, the accomplishment of any practical time division multiplex system equivalent to that used here require complex networks and more components. The lack of complexity means greater reliability for the carrier wave F.M. arrangement, with lower probability of faults and negative environmental influences. Smaller complexity also leads to lower power consumption, which together with the lower number of components used, leads to decrease in volume and weight of transmitting apparatus.

CHAPTER III

SWALLOWABLE TRANSMITTERS

3.1 INTRODUCTION:

'Swallowable transmitters or endoradiosondes' are radio transmitters used for wireless transmission of information from closed cavities or inaccessable places. Such transmitters have been developed for telemetering data where it is impossible or undesirable to connect sensing element to the recording equipment directly by tubes or wires. Endoradiosondes have opened new possibilities for physiological studies and for diagnostic examinations, since tubes or wire restrict the regions that are inaccessible. Tubes may produce physiological reflexes which disturbs the normal body functions under observation. Further, tubes may cause infection when passed through surgical openings. The endoradiosondes has none of these disadvantages.

Though in endoradiosonde techniques the distances are very short, often less than one meter, the wireless method is nevertheless indispensable owing to the presence of physical barriers between the recording instrument and the point where the measurements are to be made.

These transmitters have been termed by different investigators as 'endoradiosondes', 'radio pills' or 'capsules'

and 'swallowable transmitters'. Since the endoradiosonde implies no restriction on the organ investigated and since it is formed in analogy with other terms, it will be used here to denote any electronic device for telemetering physiological data from internal organs by wireless method.

The endoradiosonde transmitters are of two types. One is with a power source inside and is called an active transmission system. The other type does not contain a complete oscillator but consists of only a tuned circuit. Energy is supplied from an external source by means of a pulsed electromagnetic field of frequency close to that of the tuned circuit. This energy is absorbed by the tuned circuit and reemitted in a modulated form between pulses. This type is known as a passive transmission system.

3.2 PASSIVE TRANSMISSION SYSTEM:

Generally the passive transmitters are not as satisfactory as active transmitters because of the weak and unreliable signals that they produce. However, there are circumstances in which the use of passive transmission system is necessary.

In connection with the study of diseases of the eye like glaucoma, there is a need for very small, long lived, pressure transmitter that could be inserted into the eye of an experimental animal to monitor pressure changes

There are situations in which a very small animal, which can not simply carry a heavy transmitter is to be studied; the telemetry of temperature from a mice is an example [3]. It is also possible that in human beings one might wish to follow the progress of recovery from surgery by a telemetering device that could be left in the place indefinitely. For example, after brain surgery, there is sometimes a reactive rise in pressure that results in slower breathing and death; the telemetering of intracranial pressure give early warning of impending danger.

The signal strength problem is one that should be considered. Without having recourse to transformer theory, it can be said that the signal from an external transmitting coil falls of with the cube of the distance [3], and this signal is reradiated in all directions; thus that part that arrives back at the source is itself attenuated by the cube of the distance. Under these circumstances, the net falloff is with the sixth power of the distance. Any disorientation of the transmitter can result in a signal disappearance. This problem could be solved to some extent by having an omni-directional antenna in the external energising transmitter and the external receiver used outside to pick the signal. The passive endoradiosondes are easier to produce and consecuently inexpensive.

3.3 ACTIVE TRANSMISSION SYSTEM:

Because the body reacts adversely to foreign matter that is either implanted or externally attached, transmitters must be as small and light as possible. Typical accepted limits are within 1% to 2% of the subjects weight. In general the limit is set at about one gram or less [4].

Most physiological information either is directly sensed in the form of bioelectric potentials or converted into electric signals by a transducer. Either method results in low level signal in an environment ofhigh level noise. This creates need for transmitters with a dynamic range of 10^3, maximum to minimum signal ratio, and low internal noise. In addition they must have proper frequency response to cover the spectrum of generated information - usually from 0.01 c/s to about 1 kc/s [4].

For a long useful life the transmitter must be designed for minimum power consumption. Generally the power consumed must be two watts or less [4].

The transmitter must be relatively free from variations in frequency caused by power supply fluctuations. The transmission range needed for general transmitters can be fixed at 10 feet distance with an intensity of 5 microvolts at the receiving antenna terminals.[4].

3.4 TYPES OF MODULATION:

Frequency modulation is the right choice of transmission system as amplitude modulation often results in variation of the signal strength due to a change in the relative position and distance between the transmitting and receiving antennas. Pulse modulation can also be used but frequency modulation is found to be superior. A simplified F.M. system is given in the block representation of Fig.3.1.

3.5 CHOICE OF FRECUENCY:

There are no legal or licensing restrictions on the use of low powered units no matter what frequency is employed. In addition to the falling off of field strength with distance, there can be attenuation caused by the presence of any intervening conducting medium. A measure of this effect is the so called 'skin depth',which is a distance the wave travels while being attenuated to approximately one third. In case of ocean water this distance is given approximately as 240/square root of frequency. One would be able to receive the signal at atleast a distance of two or three skin depths. Physiological saline is roughly one third as conductive as ocean water.

Electromagnetic energy does not propogate in the same way through all tissues, bone, fat, muscle etc., but a

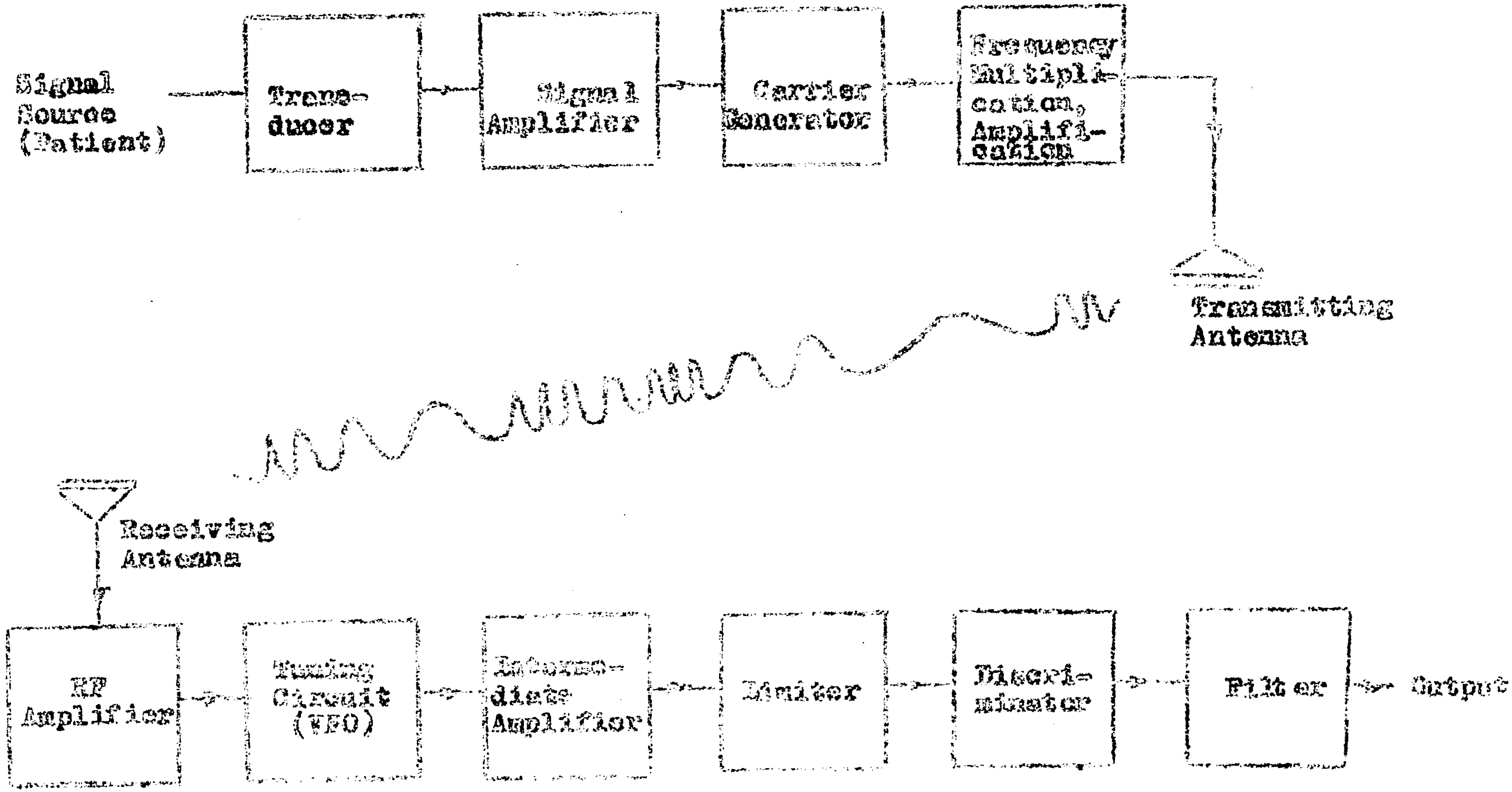


Fig.3.1 Diagram of a simplified FM radio system, as used in many modern medical applications. The transmitter consists of all the elements from the patient to the transmitting antenna. The receiver consists of all the elements from the receiving antenna to the system output.[6].

computation based on the above can only be suggestive. One would prefer very high frequencies at which tiny antennas can more effectively radiate power and yet a lower frequency would allow greater penetration through 'lossy', electrically somewhat conductive, tissues. A graph of depth of penetration vs. frequency, is shown in Fig.3.2 for muscle, blood, saline and bone.

The best choice of frequency for telemetry is better found from the experience of previous workers. Early workers in this field [5] found that frequencies from 55 kc/s to 100 Mc/s can be used. Other workers in the field [4, 6] found that frequencies below 300 Mc/s can be used, the lower limit being set by the size and weight of the coil.

3.6 TRANSMITTING RANGE:

For the same intervening conducting medium the skin depth varies inversely as the square root of frequency.

$$\delta = 5033 \sqrt{\frac{\rho}{\mu f}} \qquad [1]$$

where δ is skin depth in cm.

ρ is resistivity of conductor in ohms per cm^3.

f is frequency in c/s.

μ is permeability of medium (generally $\mu = 1$).

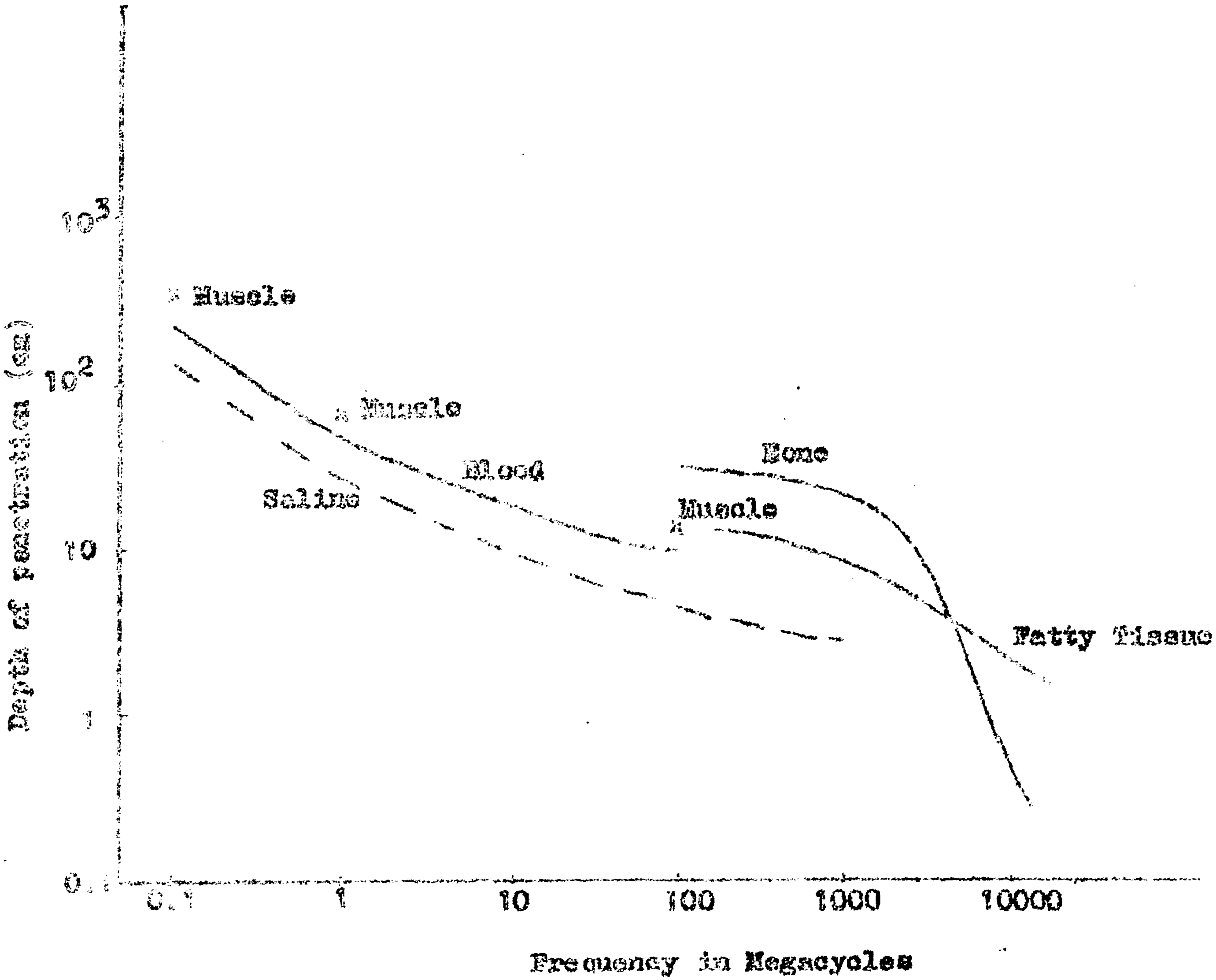


Fig.3.2 Graph of the depth of penetration versus frequency. Notice that both scales are logarithmic.

The transmitter radiation efficiency under same conditions of transmission varies directly with the square of frequency [8].

S.J.M.England and Pasmanick [9] experimentally found that a transmitter with a frequency of 6.8 Mc/s and a transmitted power of less than 200 microwatts could give 250 microvolts at the antenna terminals of the receiver placed one meter away. This easily suggests that an increase of frequency by ten times increases the range by $10^{1.5}$ which is nearly equal to 31 times.

3.7 POWER SOURCES:

The most important aspects of the power source for endoradiosonde telemetry are the capacity per unit volume and the discharge curve.

The most commonly used power source is the mercury cell because of its excellent discharge curve. The voltage remains with 1.3 volts and 1.1 volts for more than 90 percent of energy discharge. The mallory RM 312 cell has a capacity of 35 ma.hr. It is only 0.35 cm. high but its large diameter, about 0.7 cm., is a disadvantage in further miniaturization of many transmitters.

The nickel cadmium cell is also used for many purposes. It was especially common before the commercial mercury cell

became available. The nickel cadmium cell has a lower capacity per unit volume than the mercury type, but the discharge curve is equally good.

Although occasionally used, Lechlanche cells are not suitable owing to the low capacity per unit volume and the unsatisfactory discharge curve; the voltage decreases steadily throughout the discharge period.

3.8 GENERAL CAUSES OF FAILURE AND OPERATING LIFE OF IMPLANTED TRANSMITTERS:

Based on the experience of previous workers [11], it was found that component and structural failures were infrequent but every transmitter examined first, after being removed from the subject, was wet inside. Minor corrossion were present on the metal parts and the paper wrapper of the battery was soft and soggy. According to manufacturer's information, the mercury batteries used in the transmitters, absorb all the products that they generate; so they should not be the source of dampness and corrossion.

The transmitters used hitherto were sealed with five coats of tygon paint but moisture can pass through tygon. Latest transmitters [11] have been filled with an epoxy sealer, silicone rubber or vaseline to eliminate all trapped air space.

3.9 MEDICAL PROBLEMS OF INTEREST:

Some of the many variables of interest in the telemetering of physiological information from within the body are temperature, pressure, oxygen tension, pH or the acidi ty and radiation intensity.

In principle any of these can be transmitted by either passive or an active system in conjunction with a suitable transducer. Gastrointestinal motility (essentially the progression producing activity of the gut) is of interest to clinicians. Further information can be got by the simultaneous use of a number of transmitters by X-ray movies accompanying the endoradiosonde observation or by the use of radio tracking device that plots out the motion of the capsule during its passage.

A transmitter of the type used to transmit pressure in the gastrointestinal tract has also been used to transmit bladder pressures and steadiness in standing, Uterine contractions and ~~fo~~etal heart sounds and teech clenching.

A temperature sensing capsule has been used to study the incubation of penguin eggs in the Antarctic [10]. Thus we see that the field has widened the doors to research where hitherto it was never thought a feasible solution.

The significance of acidity measurements along the gastrointestinal tract is not always clear to medical men but there are experiments which they may like to perform. For example one might determine whether the administration of Vitamin 'D' to a child with rickets changes the pH in the intestine as a result of the effect of calcium. Another experiment of interest may be to investigate whether the difference in intoxicating effect of different alcoholic beverages is due to the buffering action of some and not by others.

A problem that has received some investigation is that of localising the site of internal bleeding along the gastrointestinal tract, or even of distinguishing stomach bleeding and duodenal bleeding. In a appreciable number of clinical cases this site is difficult to detect by present methods. Several approaches have been tried that would sensitise an endoradiosonde to the presence of blood. Chemical methods seem ambiguous when applied to normal contents of the tract but possibly some calorimetric method can be made to work.

A transistor with a floating base is quite sensitive to light. Thus if the cover of the transistor is removed, small changes in light intensity will produce frequency modulation of the output signal.

The pressure sensing capsule can transmit small pressure fluctuations due to breathing and even smaller ones due to arterial pulsations.

In the field of surgery one can study the restoration of normal activity after the trauma of a surgical procedure. The capsule can either be ingested in advance or it can be inserted through the wound, where it will stay until the return of normal activity.[18].

One more use of the above telemetry would be to study as to how the normal functions of the body such as metabolism, are influenced by external factors such as changes in time between meals. This could someday lead to microminature instruments that would diagnose pathologies like harmonic difficiencies and trigger the chemical or physical activities to remedy the situation [18].

Implanted microelectronics could produce more dynamic information on cardiac pathology and more precise and controlled stimulation of the heart. It could also detect the onset of epileptic seizures and diabetic shock.

CHAPTER IV

TRANSMITTER

Discussion below are detailed descriptions of endo-radiosondes sensitive to temperature, pressure and pH. Other data that can be telemetered by such miniature radio transmitter are ; partial pressures of carbon dioxide and oxygen, chloride ion concentration, enzyme activity, bioelectric potentials and intensity of ionizing radiation. Endoradiosondes have been used for the entire gastrointéstinal tract. Surgical implanted transmitters have the applicability in experimental physiology since measurement can be made for months on unrestrained and unanaesthetized animals. A consideration of some of the variables is given below.

4.1 TEMPERATURE:

4.1.1 Need for Study:

Temperature studies may have many spheres of relevance. In the human subject, there is reason to expect a temperature irregularity in the vicinity of an inflammation and perhaps near a malignancy. Hypothermia (an abnormally low body temperature) in connection with anaesthesia might be monitored by such methods. In other animals, temperature is something of an index of activity, the most dramatic examples being in cases of hibernation (the dormant state in which certain animals pass the winter in a state of reduced metabolism, muscle relaxation, and a twilight sleep). The temperature regulation of cold

blooded animals warrants special study. Warm blooded animals may have at times thermal stress, for example, birds during nesting, seals during mating and human beings on the desert or in the ocean.

4.1.2 Details of Measurements:

Transmitters for temperature measurements employ either a pulse modulation or frequency modulation. Pulse frequency modulation is the natural choice when the transistor in the oscillator circuit also serves as the transducer. A circuit based on thisprinciple is shown in Fig.4.1(a). The circuit was developed for simultaneous telemetering of pressure by frequency modulation and of temperature by pulse repetition rate of the carrier [12, 13].

For temperature telemetering, the circuit functions as follows. Oscillation is blocked for periods determined by the temperature of the transistor. The blocking action is affected by the charging of the condenser 'C' during oscillation through rectification at the emitter junction. Owing to oscillation buildup a higher charge is collected than is necessary to keep the oscillation blocked. The transistor is consequently biased off for a period during which the condenser discharges through the back biased emitter and collector diodes in parallel. Since the resistance of the two diodes is dependent to a large degree on their temperature, a pulse frequency modulation with temperature is obtained. The pulse

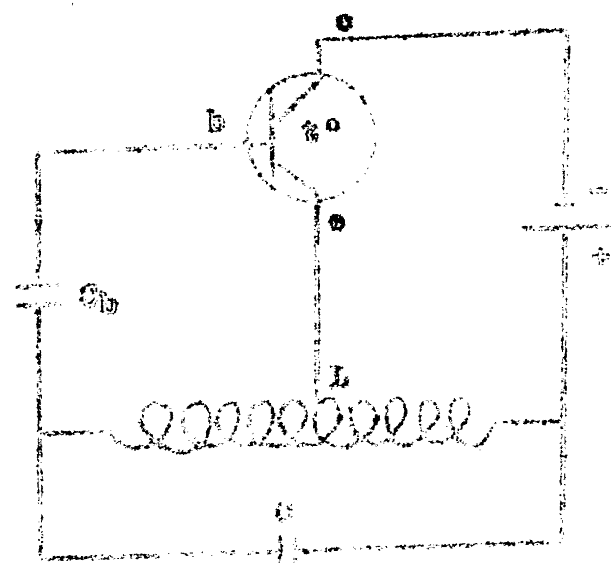


Fig.4.1(a)(Pulse Frequency Modulation)[13].

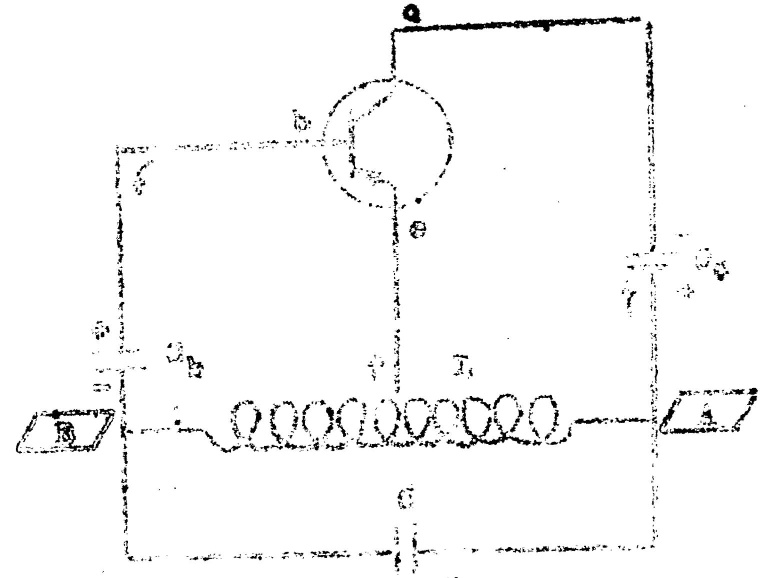


Fig.4.1(b1) [14]

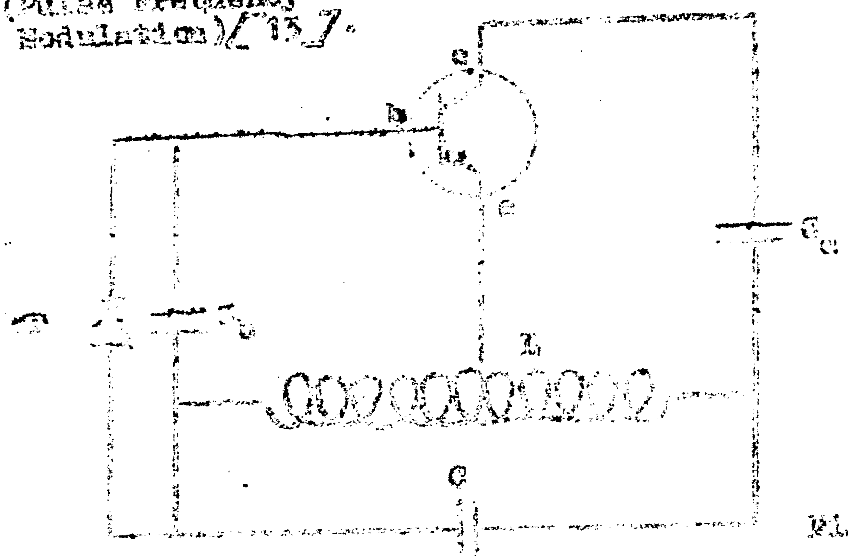


Fig.4.1(b2) (Pulse Position Modulation) [14]

TRANSMITTER CIRCUITS FOR TEMPERATURE TELEMETERING

frequency is not a linear function of temperature, however, the slope of the curve and pulse frequency vary with the battery voltage. Every transistor has its individual characteristics, and individual calibration of the transmitter is therefore necessary. Based on this principle a temperature coefficient of 10% per degree centigrade and a life time of about one year can be obtained.

A passive transmission system for telemetering temperature has been used [14]. For the sake of understanding the principle the circuit in Fig.4.1(b1) is considered. The circuit is a Hartley oscillator in which a battery is replaced by storage capacitor C_e. High frequency power in tune to the resonant circuit induces electromotive force. In the case of a pnp transistor, current due to rectifying action of the transistor flowed in the arrowed direction for a positive half cycle at terminal 'A'. The capacitor C_c and a blocking capacitor C_b are charged as shown in Fig.4.1(b1). If, now, forced input disappears, electric charge on C_b is discharge from the base to collector, and at the time the transistor changes from the butoff' to the 'on' state, oscillation is started. In other words, the circuit acts as a receiver so long as the input is present and acts as a transmitter after it disappears. The time interval between the trailing edge of the externally energized pulse and the start of the oscillation of the capsule or blocked time is approximately determined by the time constant of the base circuit, that is, product of C_b and the resistance

between base and collector of the transistor, provided that the capacitors are charged upto a constant voltage. In the case of a npn type transistor, the situation isthe same with reversing the direction of charge and discharge.

Since C_c is selected to have a minimum possible capacitance, within the range which permits oscillation, in order to reduce the size and energy required for storage. The oscillation occurs in most actual cases only once for one driving pulse.

Fig. 4.1(b2) shows the circuit of a temperature measuring capsule. The resistance between base and collector of the transistor 'TR' varies with temperature, which in turn affects the time needed in discharging the capacitor C_b, and in this way the blocked time of the capsule bears the information of the temperature within the body. The induced voltage in the resonant circuit of L and C varies for example with the relative position of antenna and capsule, thus the blocked time is affected. To reduce errors due to such an effect, a zener diode 'RD' has been inserted parallel with 'C_b'. The effect of this insertion is shown in Fig.4.1(b3) with the intensity (relative value) of high frequency external magnetic field as the abscissa and the blocked time as the ordinate.

Another passive circuit using a temperature sensitive capacitor is shown in Fig.4.1(c). In this, power is induced

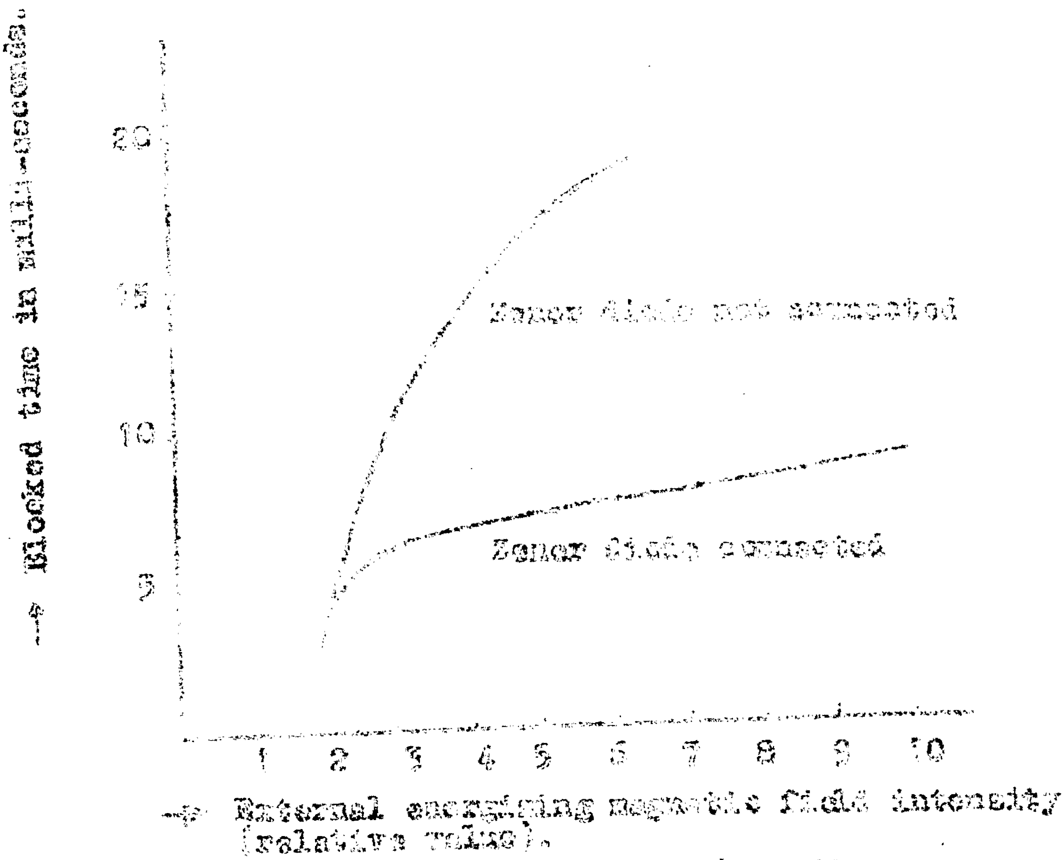


Fig.4.1(b2) [14]

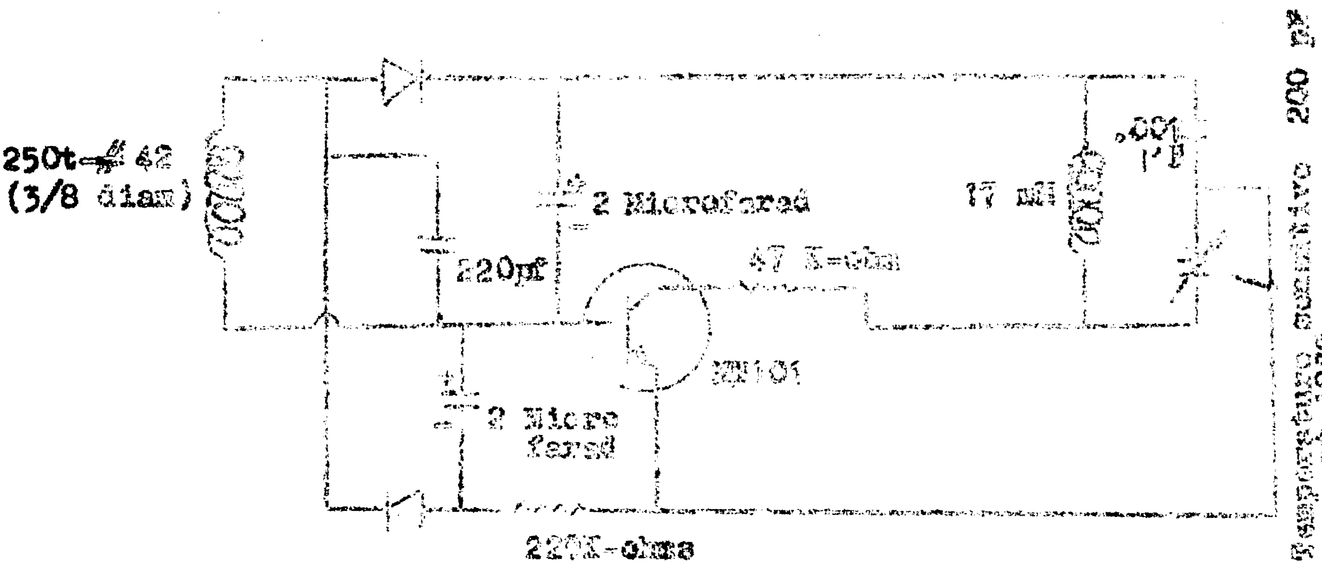


Fig.4.1(c) Illustration of an externally energized transmitter for telemetering temperature which is sensed by capacity variations. Power is induced into the full-wave voltage-doubler at 1 mc and the signal reradiated at 100 kc. [15]

into the circuit at one frequency and signal reradiated at another, rather than employing a battery.[15]. The frequency of reradiation is 100 kc/s.

4.2 PRESSURE:

4.2.1 Need for Study:

This is used to study the mild activity patterns in people actually troubled by the rapid passage of food. These transmitters are also used for testing of drugs as astrophine and have been used to study the restoration of activity after it ceased following abdominal surgery. The same type of transmitter can sense arterial fluctuations and also pressure variations in the large intestine with amplitudes somewhat larger than blood pressure. There are body cavities like the bladder in which the relatively precise magnitude and duration of brief contractions are of interest in which small transmitters are needed. The pattern of Uterine contractions under a variety of conditions would also be extremely interesting to doctors [16, 17]. Another use of this transmitter can be made to study the clenching of teeth during sleep.

4.2.2 Details of Measurement:

For pressure sensitive transmitters the variable inductance transducer has been mostly used. A membrane or metal bellows, upon which the pressure acts, is coupled to a

ferrite core or disc that moves in relation to a coil, forming the inductance, in a tuned circuit. The change in inductance with pressure produces a frequency modulation of the carrier.

Circuit shown in Fig.4.2(a1) [18] is a transistorised Hartley oscillator having a constant amplitude of oscillation and a variable frequency to communicate information. In this circuit, frequency modulation is provided by varying pressures on a diaphram moving a core towards and away from the "tank coil"; if the core is of ferrite, inward motion produces a decrease in frequency and the opposite occurs if the core is of aluminium. In the above circuit a ferrite core has been used.

A particular arrangement of the above is shown in Fig.4.2(a2). This version is perhaps the simplest and most completely described one available for construction [18]. It is approximately 0.9 cm. in diameter and 1.4 cm.long The 400 turn coil is centre-tapped and serves not only as the modulator and oscillator resonant coil but also as antenna. The diaphram can be made of rubber, but is more durable, if it is made of a plastic such as Saran. Most of the restoring force of the core is provided by the compressibility of the gas behind the diaphram, from which leakage must be prevented. The calibration thus is relatively independent of the changes in the elastic properties of the diaphram because of contact

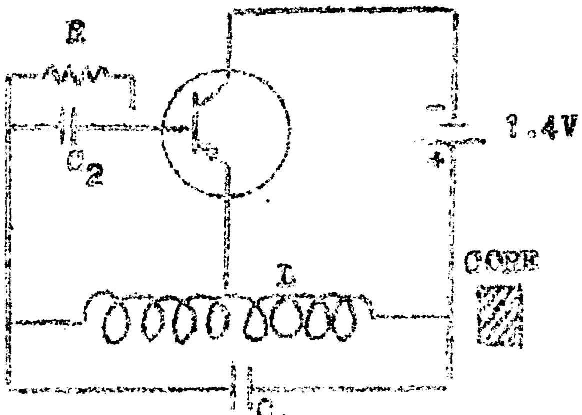


Fig.4.2(a1): Diagram of the induction field active radio transmitter circuit that is frequency modulated by changes in core positions in response to pressure changes. [16]

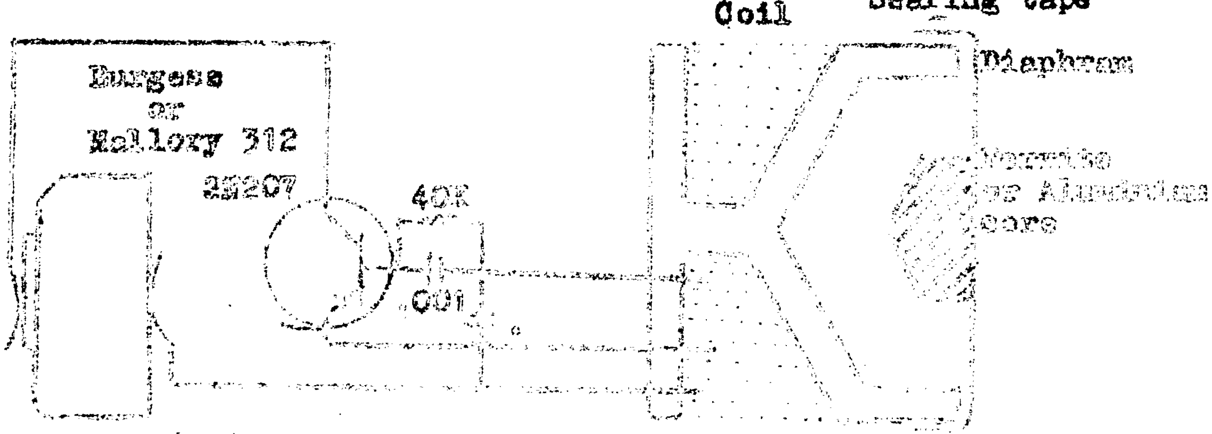
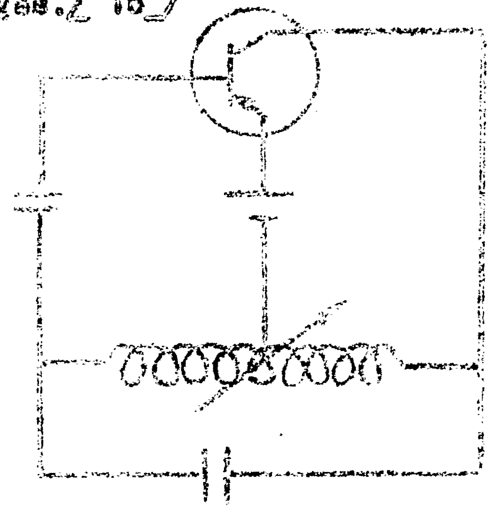


Fig.4.2(a2): A specific endoradiosonde arrangement based on circuit of Fig.4.2(a1) [16]



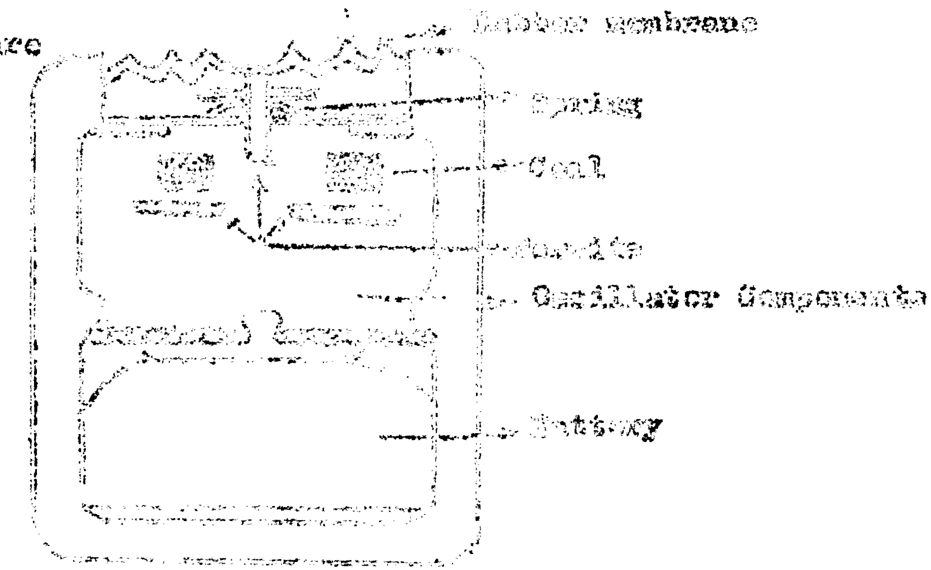


Fig.4.2(b)
A circuit for pressure telemetering used by Jacobson and Mackay [19]

with body fluids. This unit has performed well in the routine studies of human peristaltic (nature of the wormlike movement by which the alimentary canal or other tubuler organs provided with both longitudinal and circular muscle fibres propel their contents) patterns.

Another circuit for telemetering pressure has been shown in Fig.4.2(b) with the cross-sectional view of the capsule [19]. The circuit shown is a Hartley oscillator circuit. This circuit has made it possible to build compact endoradiosondes. The transducer is linear. The low frequency drift with temperature has been obtained by compensating for the expansion of air with the capsule by using an oscillator circuit with a negative temperature coefficient. The volume of the transmitter is one cubic centimeter and it has a life of three weeks. The transmitting ranges about 15 to 30 cms. depending on interference level.

4.3 BLOOD PRESSURE:

4.3.1 Need for Study:

A physiological parameter of interest is blood pressure. For some purposes, it is sufficient to know systolic and diastolic pressure along, whereas in other situations, it is of interest to have complete pressure as a function of time. Arterial pressure has been measured through the intact wall of a blood vessel using the principle of Mackay Marg tonometer

for eye pressure measurement [20].

In essence if a body cavity is pressed against a forced transducer that is coplanar with a surrounding flat insensitive annulus until tissue flattering extents into the annulus, then intracavity pressure alone will be indicated independent of such variables as tension in the intervening tissues and bending forces therein. A unit constructed hitherto for implantation in contact with an artery is shown in Fig.4.3(a). Absolute pressure is to be transmitted and thus long term stability is desired. Since the air trapped in the transmitter cannot equilibrate with the outside, readings must be corrected for barometric changes [21].

Circuits with this transmitter is shown in Fig.4.3(b) and Fig.4.3(c). Circuits of thistype can run for a very long time on a single battery such as is used in power electric watches since the total current drain for adequate transmission through the body wall need only be a few microamperes. In the case of the circuit of Fig.4.3(b), the current drain can further be reduced from a total of 3 microamperes by increasing the 100 kilo-ohm resistor; radiated power correspondingly decreases. The 6.8 kilo-ohm resistor makes the oscillator frequency rather independent of voltage and temperature changes. The same circuits can be modulated by changing the 100 pf. condenser shown in the tank circuit rather than by changes in inductance.

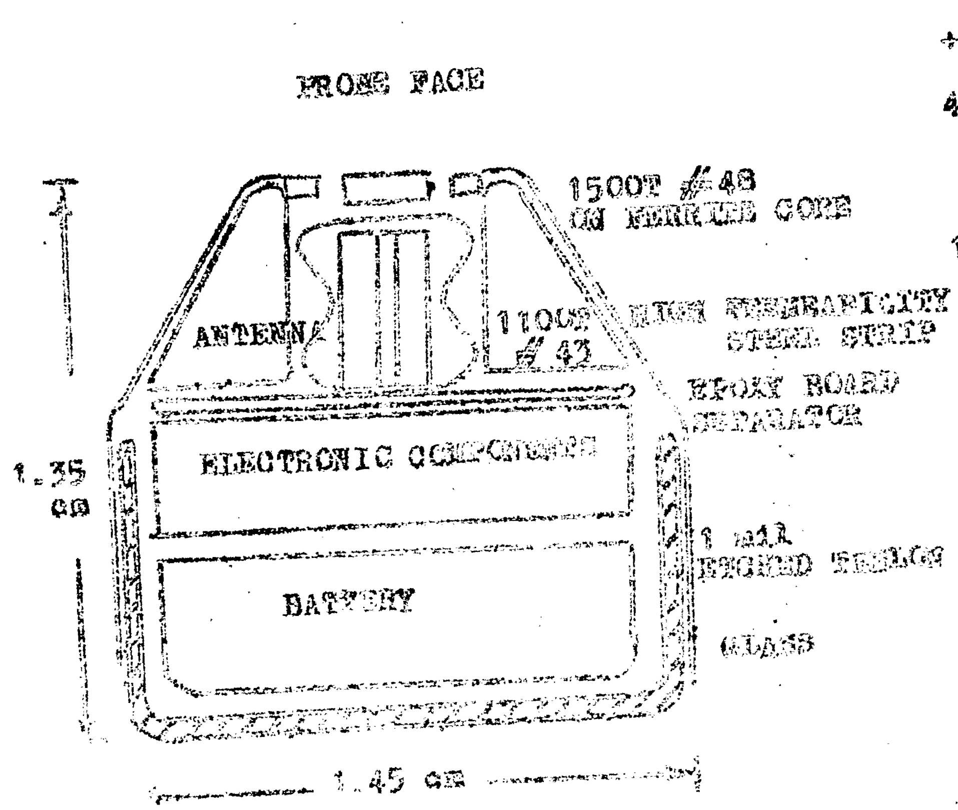


Fig:4.3(a): A unit for telemetering blood pressure [2]

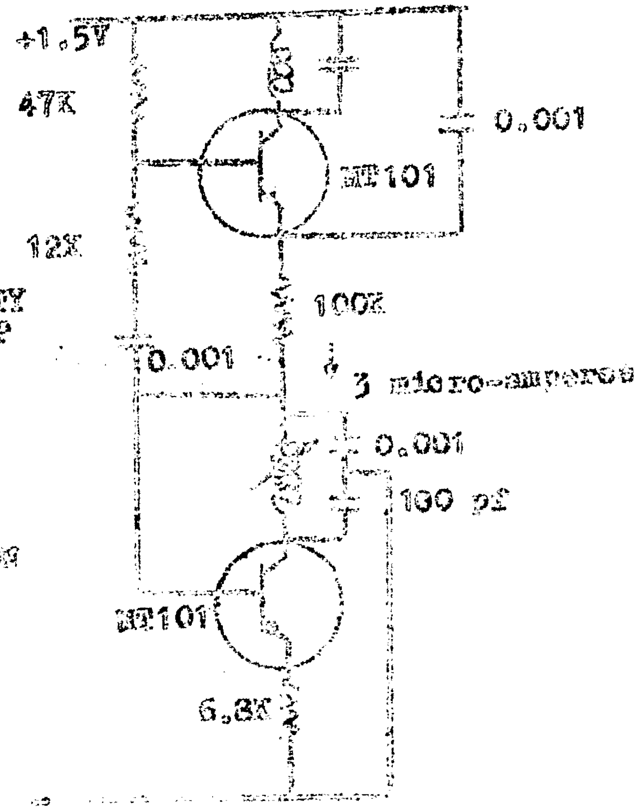


Fig.4.3(b): Illustration of stable low current transmitter. Circuit used by Mackay [21] for transmitting blood pressure.

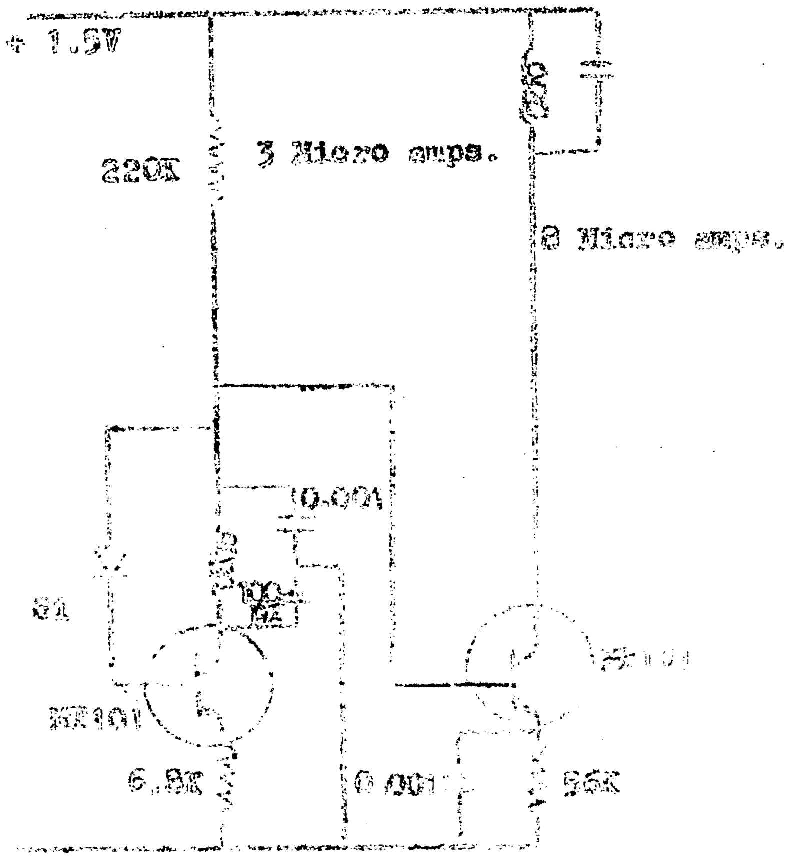


Fig.4.3(e): Illustration of a stable low current transmitter circuit used by Mackay [21] for transmitting blood pressure.

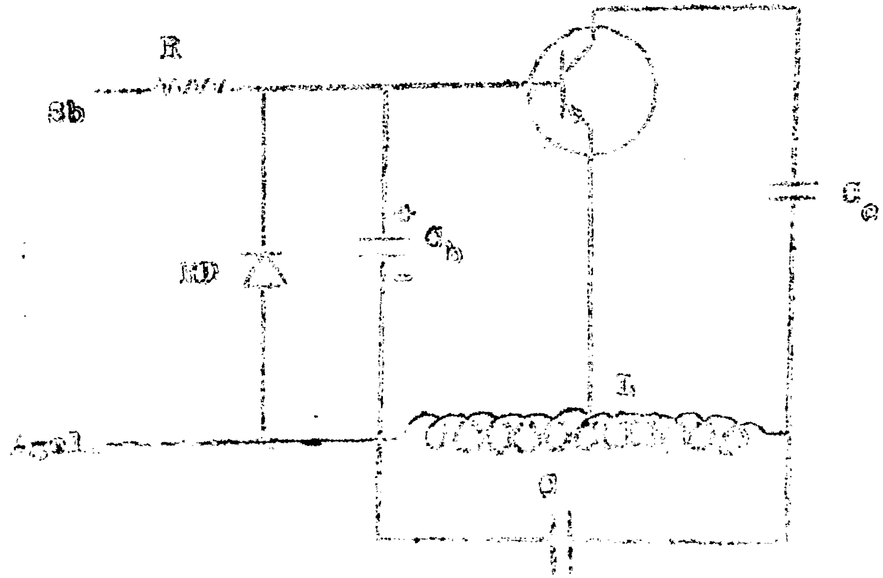


Fig.4.4(a) Circuit for transmitting pH used by [illegible] et al [14].

4.4 pH OR HYDROGEN ION CONCENTRATION:

The presence of various chemical elements can be determined by the use of suitable electrodes. The proper use of these electrodes poses a common problem and this chemical analysis for several things including sodium ion, pottassium ion etc. are needed.

The first pH sensitive endoradiosonde employed a mechano chemical transducer [12]. It consisted of a pressure sensitive transmitter combined with a polymer that changed its physical dimensions with pH. The disadvantages of this method were slow response, low accuracy and large salt errors.

A pH measuring echo capsule that is a passive one is shown in Fig.4.4(a). When the voltage of pH measuring electrode is applied across a capacitor C_b, the blocked time of the capsule is varied following the variation of the voltage in the pH measuring electrode. In the case of temperature measuring capsule, temperature dependence of the capsule itself could be used effectively but in measurement other than temperature the reduction of this effect is necessary.

4.5 BLOOD DETECTION:

The problem of blood detection is of great medical interest because of the difficulty of locating a haemorrhage in the alimentary canal. In the course of a general research on the endoradiosondes, a new method of bleeding detection, slightly modifying a temperature measuring endoradiosonde was found. [26].

4.5.1 Principle of Bleeding Detection:

The principle of this method is based on the fact that an enzyme, catalase, is present in 'enthrocyte', and has the property of catalysing the decomposition of hydrogen per oxide. Accordingly, when the hydrogen peroxide is mixed with blood, the hydrogen per oxide will be decomposed into water and oxygen, with the simultaneous production of some heat of reaction. The chemical reaction follows

$$H_2O_2 \quad H_2O + \tfrac{1}{2}O_2 + 23.1 \text{ calories of heat} \qquad (1)$$

Either the oxygen or heat generated may be used to detect the blood present in the gastrointestinal tract due to the bleeding condition. The measurement of temperature rise is easier and has been discussed earlier. Temperature measuring endoradiosondes were modified to accommodate a solid peroxylate such as sodium perborate which may communicate outside through a reticule window having dimensions such

as substantially to prevent the solid state peroxylate from spilling out from the cavity.

The weight of the fine grained sodium perborate accommodated in the cavity has been about 0.1 gm.; it generates about 15 calories when decomposed completely. The reaction formula in this case is as follows:

$$Na\ BO_2.\ H_2O_2.\ 3H_2O \qquad Na\ BO_2 + 4H_2O + \tfrac{1}{2}O_2 + 23.1\ cal. \quad \ldots (2)$$

Any temperature measuring endoradiosonde can be used to measure the temperature rise.

4.6 TUNNEL DIODES FOR MEDICAL RESEARCH:

A tunnel diode is a pn junction where the p and n sides are doped to degeneracy. When impurity atoms are $10^{19}/cm^2$ and junction width is 100°A., it was found by Leo Eskaki in 1958 that the forward characteristic changes drastically. The reverse characteristics also changes in that it conducts heavily in the reverse direction.

A typical tunnel diode current voltage characteristic is shown in Fig. 4.6(a). In the section 'bc', the current decreases as the voltage increases. Thus the device exhibits incremental negative resistance. In a device having V.C.N.R. (voltage controlled negative resistance) for a given voltage, there is only one current whereas for a given current there

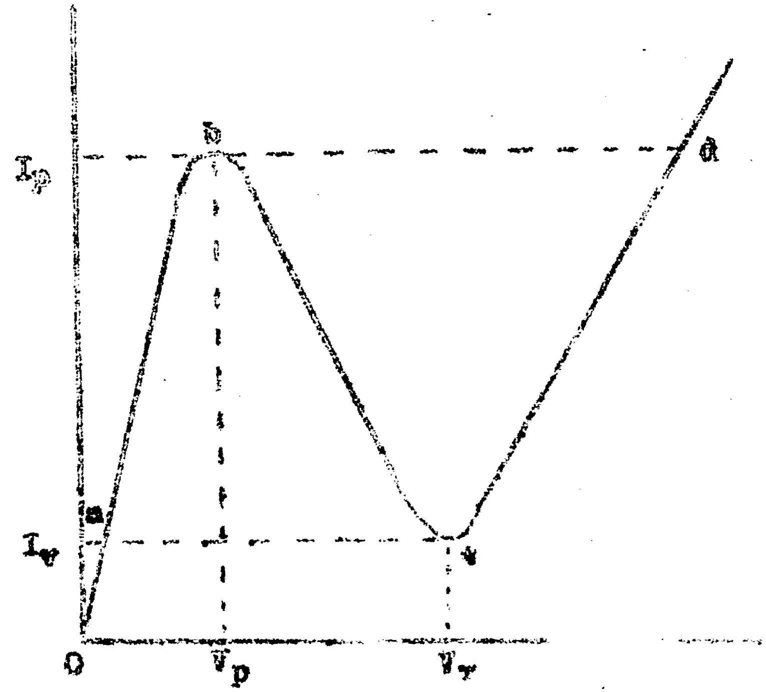


Fig.4.6(a) Current voltage static characteristics of a tunnel diode.

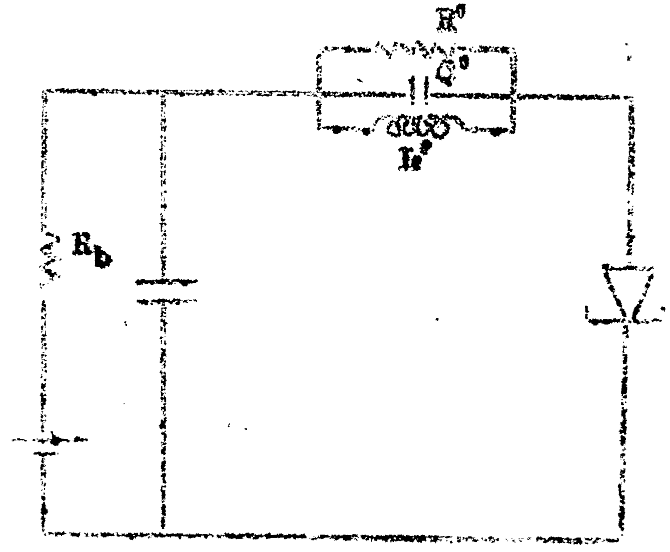


Fig.4.6(b)

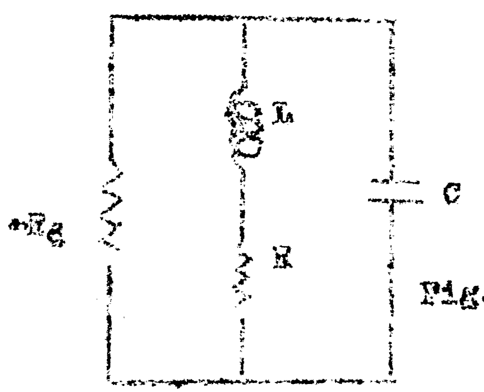


Fig.4.6(c)

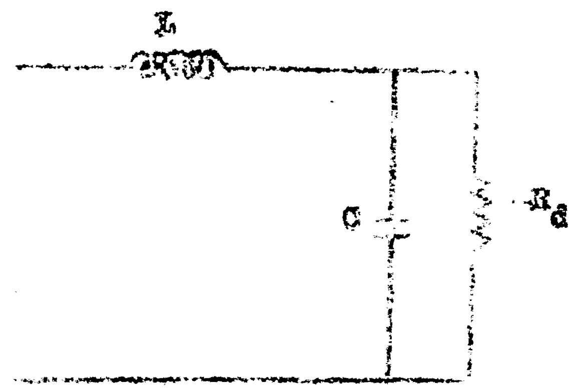


Fig.4.6(d)

TUNNEL DIODE F.M. OSCILLATOR MODULATOR [22]

may be as many as three voltage points on the static characteristics. Thus, to plot the static characteristics we use a voltage source. In the region 'bc' the tunnel diode can be used as an active device.

There are three types of tunnel diodes. They are Germanium tunnel diodes, Indium antimonide tunnel diodes and Gallium arsenide tunnel diodes. Where as the voltage scale is decided by the material used in the construction, one can get tunnel diode of different peak currents. With the use of tunnel diode, transmitters as small as about 0.8 cm. diameter and 0.2 cm. length has been constructed [4, 22].

The fundamental circuit of a tunnel diode oscillator modulator is shown in Fig.4.6(b). R' represents the radiation resistance and R_b the other losses in the circuit. The A.C. equivalent circuit of the oscillator is shown in Fig.4.6(c). The steady state energy supplied per cycle by the $(-R_d)$ of the tunnel diode is equal to the loss per cycle in the equivalent resistance R. The oscillating frequency is determined by L, C and R. The value of L may be assumed to be constant. Because the tunnel diode capacitance varies with the bias, the equivalent 'C' is a function of the bias voltage V. The total resistance 'R' depends strongly on the bias when the tunnel diode is operating at either end of the negative resistance region. As the bias 'V' moves away from the centre of the

negative resistance region, the oscillation extends into the positive resistance region of the tunnel diode. Therefore, the loss per cycle increases and the oscillating frequency decreases [22]. The frequency vs. bias characteristic is the combined effect of R and C. It varies over a considerable range depending upon the tunnel diode used in the oscillator.

It has been found [22] that smaller the capacitance used, the higher is the sensitivity. Thus the circuit provides very sensitive means to produce F.M. radio waves. It has been found that circuits with tunnel diodes could be made as small as 0.2 cubic centimeter with a transmitting range of 20 feet with a 14 db. gain receiving antenna [4].

Figures 4.6(e), 4.6(f) and 4.6(g) are the circuits for tunnel diode oscillator that has been used hitherto [22]. Circuits 4.6(f) and 4.6(g) were developed from that in 4.6(e). These two circuits provide low bias voltage to the tunnel diode as well as good impedance match. With the circuit in 4.6(f) an output impedance of about 30 ohms and an input impedance of about 6000 ohms can be obtained. With the circuit in 4.6(g), the output impedance can be made less than 30 ohms while an input impedance of more than 20,000 ohms can be obtained. The circuits in Figures 4.6(f) and 4.6(g) also reduce the current

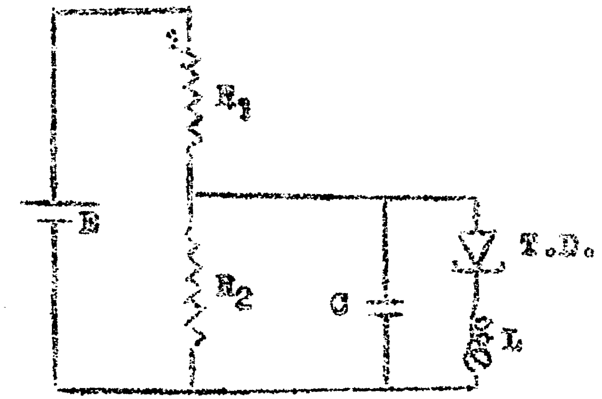


Fig.4.6(e)

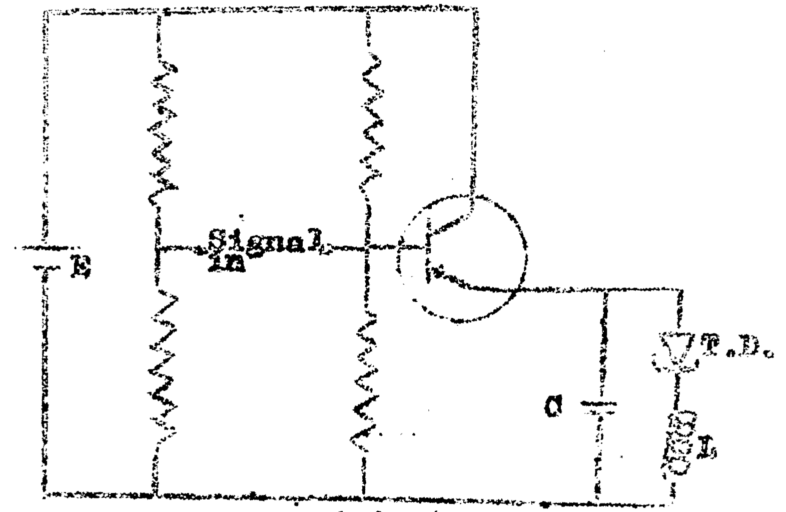


Fig.4.6(f)

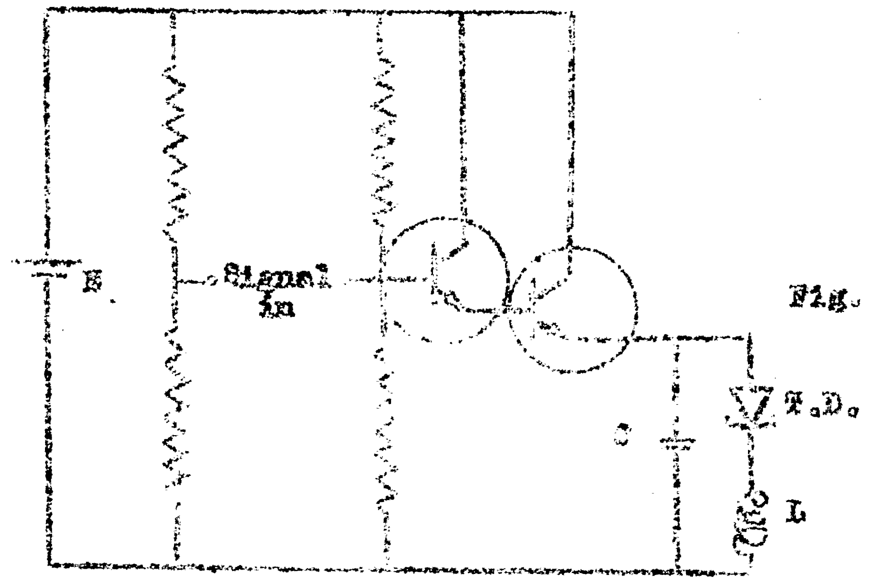


Fig. 4.6(g)

BIAS AND INPUT CIRCUITS OF TUNNEL DIODE TRANSMITTERS USED BY WEN KHO AND L.SLATER

drain from the battery compared to the circuit in Fig.4.6(e). In order to obtain very low frequency response and reduce the size of the unit, a d.c. coupling bridge has been used for the input in Figures 4.6(f) and 4.6(g).

CHAPTER V

RECEIVING SYSTEMS

Several standard methods for detecting frequency modulated signals have been used for endoradiosonde application. The heterodyne or the superheterodyne principles are most commonly employed methods because of their simplicity. The received signal of unknown frequency is mixed with a local oscillator signal and the resulting difference is recorded, its deviations are equal to those of the received signal. One disadvantage of such receivers is that the frequency range is limited by the bandwidth and any increase in it is accompanied by an increase in noise. Moreover, the heterodyne method has inherent ambiguity that the same beat frequency is obtained if the unknown signal lies above or below the standard frequency.

The most accurate method for reception is to employ a digital counter. Each period of the carrier is counted after amplification for consecutive gated periods. Each gated period is accurately determined by counting down from a crystal oscillator. The changes in the counts in each period is a measure of the frequency deviation of the carrier.

The receiving system mentioned has an inherently bad signal to noise ratio because the frequency modulated signal has to be amplified in a broad band amplifier. Consequently

such receivers require high field strengths. The larger the frequency deviation of the carrier, the greater must be the bandwidth and the lower is the signal to noise ratio.

Jacobson and Lindberg have specially developed a receiver [23] for frequency modulated signals from endoradiosondes. The drift of the receiver is within ± 20 c/s per day.

5.1 DISCUSSION OF THE RECEPTION PROBLEM:

The desirable properties of a radio receiver are determined by the nature of the signals to be received. The biological processes, studied by endoradiosonde techniques, usually have low frequencies (100 c/s to 1 cycle a day). For example the frequency of the pressure changes in the body during heart activity is about 1 c/s and the frequency of the pressure changes in the stomach during food digestion is about 0.05 c/s. Some temperature variations in the body occur at the rate of one cycle a day. The slow nature of these processes put severe restrictions on the permissible overall drift of the transmission system employed. Since the space is highly limited it is difficult to incorporate any of the frequency stabilising circuits usually employed in transmitter oscillators. Therefore a certain frequency drift in the oscillator must be tolerated. If this drift is not to destroy the accuracy of the method, the signal deviation should be

made correspondingly larger. A carrier frequency deviation of atleast 10 percent is often desirable.

The signals from the endoradiosondes are normally as low as 5 micro-volts at a distance of 12 feet from the transmitter. This is due to the fact that power drain of the transmitter must be of the order of two milli-watts or less to ensure a long life of atleast a few days for the power source. To obtain a signal to noise ratio of atleast 50 [4], necessary for the interception of weak signals the receiver must have a sensitivity of about 1 micro-volt.

With a conventional endoradiosonde receiving antenna, consisting of a single coil, the receiving intensity may vary abruptly with changes in the mutual direction of the transmitting and receiving antennas. This problem being special to endoradiosonde telemetry of biological information, a non-directional antenna will be suggested at the end of this chapter. The problem of fetting the right sensitivity and good selectivity is a problem same as that for any conventional receiver. The only difference being that the output of the discriminator of the F.M. receiver instead of being amplified by an audio amplifier, whose response generally starts from about 50 c/s, we use a d.c. amplifier so that frequencies right from nearly d.c. to about 1 kc/s are amplified to finally drive either a pen recorder or an oscilloscope display.

Thus for most of the endoradiosonde reception a standard frequency modulation receiver employing several stages of radio frequency amplification and frequency modulation discriminator or ratio detector is sufficient. In most of the cases, the output of the discriminator is itself sufficient for an oscilloscope display or even to drive a pen recorder.

Typical values for the receiver parameters that would be sufficient for practical use are:

1) Input sensitivity - 5 micro-volts (r.m.s.) input signal for a signal to noise ratio of ten at the receiver output.

2) Total system gain of 2×10^4 for a 10 micro-volts signal is sufficient.

3) Dynamic range of input to the receiver = 1 micro-volt to 2 milli-volts.

4) Linearity of discriminator - about 0.5%.

5) Frequency response - from 0.01 c/s to 2kc/s normally. For special purposes a response upto 20 kc/s may be desired.

6) Input impedance of about 6 kilo-ohms is sufficient.

7) Minimum output S/N ratio - 10 db normally.

8) Noise figure - 15 db (for most receivers).

These values have been obtained from the receivers that were successfully used in this work hitherto.

5.2 OMNIDIRECTIONALITY OF RECEIVING ANTENNAS:

As the transmitting antenna reorients itself with respect to the receiving antenna, either because of the motion of the subject with respect to the receiver or because of the motion of the transmitter within the subject, the signal can disappear because of loss of coupling between the two coils. One can surround the subject with three or more perpendicularly or otherwise oriented receiving coils in order to ensure that atleast one will contain a signal under all circumstances. The description about such a system is given by R.S.Mackay [24].

In Fig.5.1(a) a two dimensional situation is depicted in which the output field of the transmitter can take directions 1, 2, 3 withim perpendicularly oriented coils AA and BB. In position 1, most of the signal is induced in coils AA (which are connected in series) and little in coils BB. In position 2 all of the signals is induced in coils AA. In position 3, most of the signal is again induced in coils AA and then again a small signal is induced in coils BB but now we see that the phase of the signal induced in coils BB is 180° from the signal in coils BB in position 1. Thus if the two sets of coils are all, for example connected in series so that for one position the signal in the two sets will add, then for some other position of the transmitter the signals will subtract. For

one range of positions the signals can become vanishingly small. The three dimensional situation is quite similar when a third set of coils is oriented with its axis perpendicular to the plane of the page. Thus one would desire some circuit arrangement that would give a signal which would be quite the same after a change of 180° of the phase of the incoming signal.

A sinusoidal signal that is fully rectified has the property that the former positive and negative peaks lose their identity. One can similarly employ any frequency doubling circuit and in general any even harmonic of the signal will be satisfactory in removing the phase sense. In Fig.5.1(b) are shown three perpendicularly oriented receiver coils, each feeding a frequency doubler. The doublers can be regarded as full wave rectifiers, with gain. This can also be thought of as equivalent to the type of frequency doubler which, using a pair of identical transistor, would employ push-pull bases and parallel collectors. The outputs are mixed in a resistive adding circuit before transmission to the receiver. The receiver then senses variation in the doubled frequency just as it otherwise would have sensed variations in the original frequency. There is no orientation of the transmitter for which the signal disappears.

Since $\cos 2wt = 2\cos^2 wt - 1$, it can be seen that this process can be alternatively considered as taking the sum of squares of the three orthogonal components of the transmitter

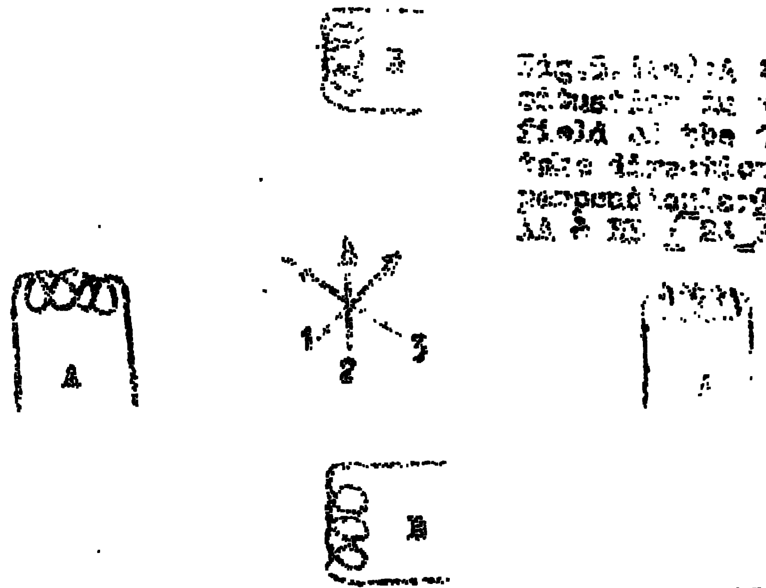
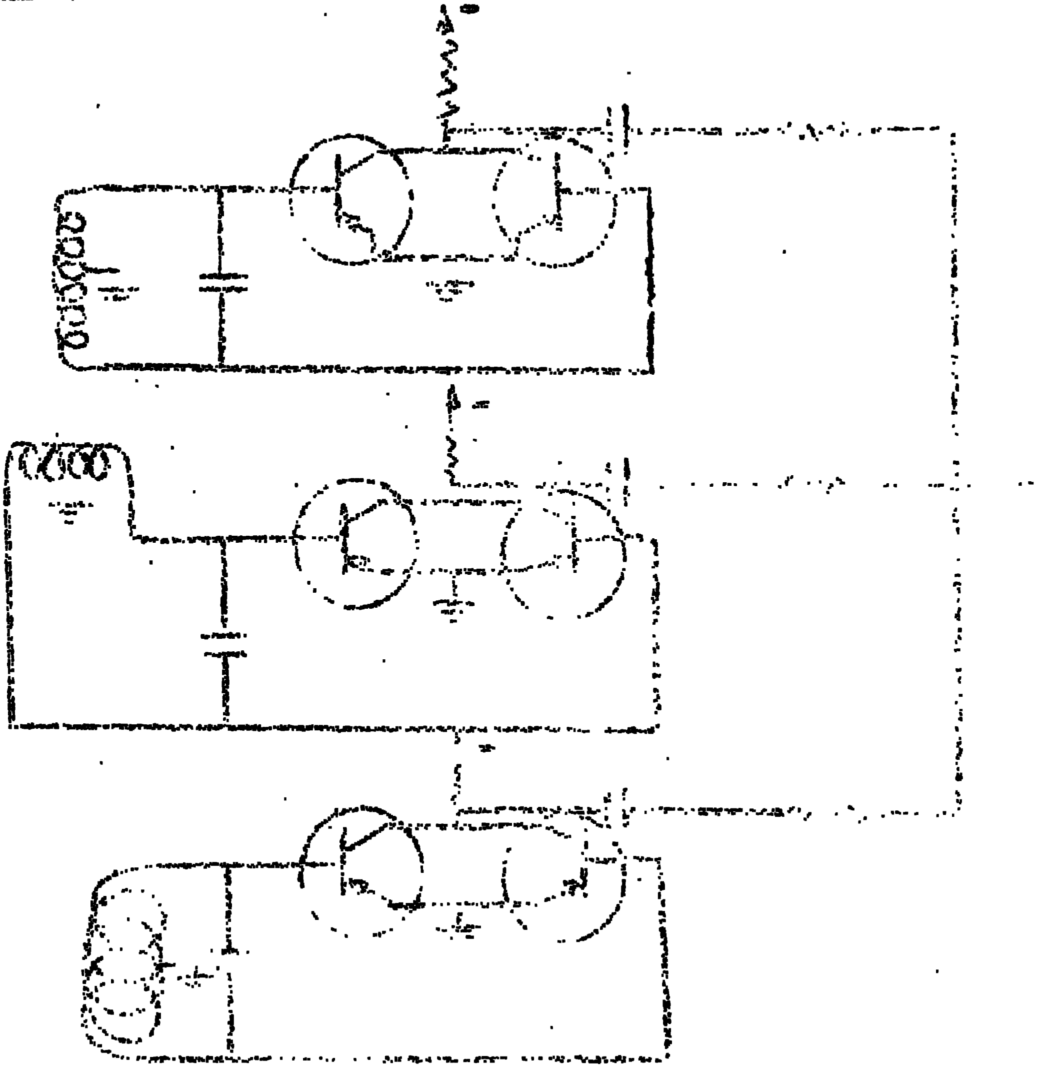


Fig.3.1(a): A two dimensional situation in which the output field of the transmitter can take directions 1, 2, 3 within perpendicularly oriented coils AA & BB [2[illegible]]



[illegible].1(b): Diagram of three orthogonal antennas each feeding a [illegible]uency doubler or squaring circuit before combining the signals [illegible] presentation to one or more receivers. This circuit was [illegible] by Mackay [24].

field in space to give the square of its magnitude, independent of orientation.

The receiving loops are being shown tuned to the fundamental transmitter frequency so that any second harmonic already present will berejected. Otherwise part of the signal will be fed through the doubler circuit unchanged and will interfere with the desired action because this double frequency signal does not have the phase insensitive property. Even in the three coil case there are only two possible phases which appear the same after full wave rectification or after conversion to second harmonic or other even harmonics. In order to produce a change in frequency a non-linearity must be present. The signals produced by the transmitter will often bring the circuits into their non-linear range. However with the attenuation produced with the weakening of the signal, an extra stage of amplification has to be interposed between the antenna and the frequency doubler if the action is to be certain.

The signal from this antenna goes to the receiver where the conventional blocks are shown in Fig.5.1(c). The signal first undergoes an amplification in the R.F.amplifier stage before it is mixed and got to a standard I.F.frequency. The gains of stages are chosen so as to get the required sensitivity. The procedure for design is same as that for any conventional F.M.receiver. The narrow band I.F.

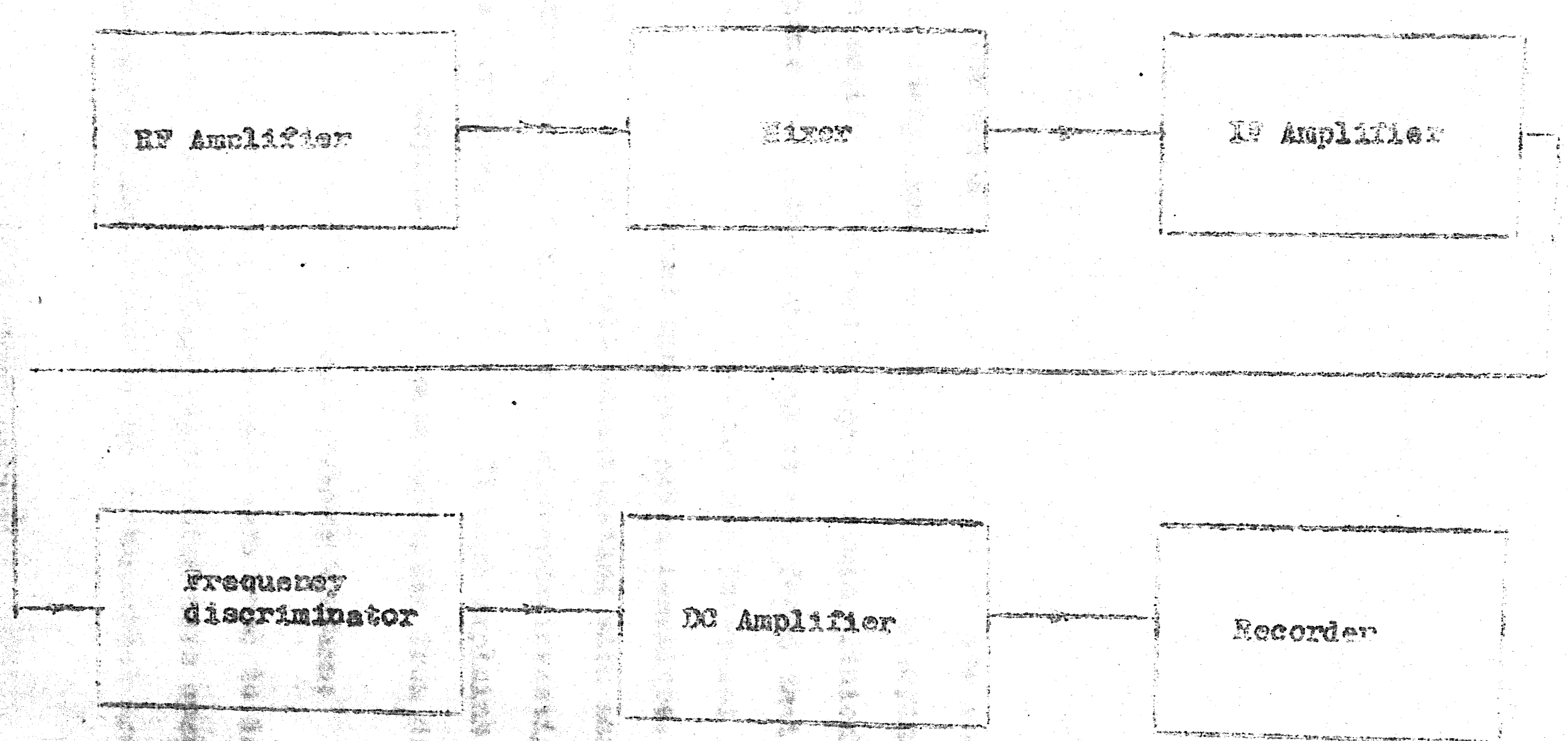


Fig.5.1(e): Block diagram of a general receiver which is also applicable for endoradiosonde reception.

amplification gives the required noise rejection. The output of the I.F.amplifier is fed to the discriminator which senses the information contained in the frequency deviation. The difference for endoradiosonde telemetry comes only at this stage. If the output power of the discriminator is not sufficient to drive the recorder, which is rarely the case, a stage of d.c.amplification is necessary before driving the ink recorder or feeding for an oscilloscope display.

5.3 IMPORTANCE OF TRACKING THE RADIO PILLS IN THE HUMAN BODY:

The speed and type of movement of the radio pill through the alimentary canal are of interest in studying various diseases and the action of certain drugs. Though clinical studies in these directions are being conducted it was found that the speed of propulsion through the intestines was increased in patients with diarrhoea and in normal subject given laxatives. It is strongly believed in medical circle investigating with sondes that with an automatic tracker for the endoradiosonde, investigations about the disease diarrhoea can be made. It also explains the action of drugs like Morphine to patients suffering from diarrhoea [25].

5.3.1 Principle of various Tracking Systems:

Hitherto X-ray techniques were used to detect the presence of sondes as they contained parts which were opaque to these rays. But extended or continuous X-ray examinations are very undesirable

because of radiation hazards. A system for tracking and recording the position of the radio pill is needed.

We know that the active endoradiosonde generates radio waves. The field strength of these waves decreases with increasing distance from the sonde - as does the intensity of any radiation with increasing distance from the origin. Here it should be noted that the type of aerial used should be an omnidirectional type aerial for it should not mistake the low field intensities picked up by the non-directional aerial to the fact that the sonde is away from the aerial whereas in reality it may not be so. Using the non-directional aerial we can say that when the aerial is moved towards the radio pill the field strength meter will show an increasing signal, and a decrease will be observed when the aerial is moved away from the pill. The point for maximum field strength corresponds to the closest approach to the pill. This manual tracking system is not good enough because it is tedious procedure and not very convenient. It does not permit the production of a map showing the passage of the radio pill. Also it is not possible to get accurate correlations between the movements and telemetered data by such manual tracking. Consequently a servo system that automatically tracks has been given.[25].

The automatic tracker employs a principle similar to that used in modern radar technology. Just as a radar aerial can

be made to swirl so that it automatically follows the movements of the radio pill. The trick that makes this possible is to put the aerial into constant rotation around a shaft with a speed of about one revolution per second. The rotation occurs in a plane parallel to the abdominal surface. The resulting variation in the field strength - owing to the varying distance to the pill - is detected by the receiving system, which actuates two servo motors. The aerial carriage automatically seeks a position where the signal strength is constant during the rotation. This situation occurs when the rotation axis passes through or is near the position of the sonde.

In this way the aerial carriage follows the sonde on its way through the body. A map of this movement is drawn by an ink pen attached to the carriage on a piece of paper supported by a curved plexiglass plate resting upon the abdomen [25]. This map is useful in the investigation of a number of diseases.

Thus we see that not only the information from the pill but also the nature in which it descends down a system gives greater insight in medical problems where lack of proper equipment prevented men in the medical field to investigate further.

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